

## Stabilizing Device, Vehicle Equipped Therewith, and Stabilizing Method

### BACKGROUND OF THE INVENTION

5       The present invention relates to a stabilizing device for stabilizing a vehicle with regard to driving dynamics, having presetting means for determining a setpoint yaw rate signal, having limiting means for determining a limiting yaw rate signal which represents a maximum yaw rate of the vehicle, such that the vehicle remains stable while taking into account the maximum 10 yaw rate, and for limiting the setpoint yaw rate signal to the limiting yaw rate signal when the value of the setpoint yaw rate signal exceeds the value of the limiting yaw rate signal, and having generating means for generating a steering intervention signal and/or at least one braking intervention signal by reference to the limited setpoint yaw rate signal. The invention also relates to a single-track or multitrack vehicle having such a stabilizing device and to a method with 15 the mode of functioning of such a stabilizing device.

Such a stabilizing device is known, for example, in the context of a driving dynamics controller of a vehicle, for example of a passenger car, from the article "FDR-Die Fahrdynamikregelung von Bosch [FDR - the driving dynamics controller from Bosch]", ATZ Automobiltechnische Zeitschrift 96 (1994) 11, pages 20 674 to 689, editor Anton van Zanten, Rainer Erhardt and Georg Pfaff. The control concept of the known driving dynamics controller is based on the so-called single-track model in which a setpoint yaw rate is calculated from the speed of the vehicle and from a presetting steering angle which the driver

presets at a steering handle. However, if an excessively large setpoint yaw rate is selected the vehicle could not travel along the desired curved path due to the wheels' frictional properties being too low or the like, for example, if the setpoint yaw rate is limited by the driving dynamics controller. The interventions of the 5 driving dynamics controller in the brakes and/or the engine of the vehicle take place on the basis of the limited setpoint yaw rate. In order to determine the setpoint yaw rate, the presettings of the driver of the vehicle with respect to the steering angle and the drive torque and braking torque, the estimated speed of the vehicle and the coefficient of friction of the wheels are evaluated.

10 DE 101 30 663 A1 discloses a method for preventing tilting for a vehicle in which a setpoint value for the yaw rate of the vehicle is calculated on the basis of measured input variables and compared with a measured actual value, in which case, in accordance with the comparison result, the wheel brakes of the vehicle are actuated so that the actual value of the yaw rate assumes the calculated 15 setpoint value. The input variables are, inter alia, a lateral acceleration of the vehicle which is sensed, in which the calculated setpoint value of the yaw rate is reduced as a function of the sensed lateral acceleration if that acceleration exceeds a critical value.

DE 198 30 189 A1 proposes a method for increasing the lateral tilting 20 stability of a vehicle. This method is used, inter alia, in conjunction with a system for controlling yaw moment, in which the yaw moment controlling system adjusts the yaw rate of the vehicle to a determined setpoint value. The determined setpoint value is limited to a physically appropriate value, whereby

the limiting takes place taking into account a predefined stability condition which includes, inter alia, the lateral acceleration of the vehicle.

EP 1 000 838 A2 also relates to a method for controlling the lateral dynamics of a vehicle with front-axle steering in which a first setpoint value for 5 the yaw rate of the vehicle is determined on the basis of variables which represent the instantaneous movement state of the vehicle, the setpoint value corresponding to the driver's request relating to the path movement of the vehicle, with the request being applied by activating a control element. In addition, under the secondary condition that the attitude angle in the region of 10 the rear wheels of the vehicle should not exceed a specific value, a second setpoint value is determined for the yaw rate, so that the yaw rate of the vehicle is set to the respectively lower of the two setpoint values. Depending on the driving situation, the yaw rate is set by actuating a steering angle actuator and/or at least one of the wheel brakes of the vehicle.

15 The object of the invention is to improve a stabilizing device or a method of the type mentioned at the beginning to the effect that a risk of tilting of the vehicle is reduced.

In order to achieve the object, with the stabilizing device of the type mentioned at the beginning there is provision for said stabilizing device to have 20 actual value means for making available a tilt angle signal which represents the current tilt angle of the vehicle, said actual value means being embodied in such a way that the tilt angle signal contains the current tilt angle or the current tilt angle can be determined from the tilt angle signal, and for the limiting means to

contain tilt angle means for determining the limiting yaw rate signal by reference to the tilt angle signal. In a corresponding way, a vehicle according to the invention and a method according to the invention are configured in accordance with the technical teaching of a further independent claim.

5       The tilt angle, sometimes also referred to as the rolling angle, describes the rotational deflection of the vehicle about its longitudinal axis. Taking into account the tilt angle in the determination of the setpoint yaw rate signal which is the maximum permitted prevents the vehicle from tilting or even rolling over. The generating means are, for example, a yaw rate controller. The steering  
10 intervention signal controls, for example, a steering actuator for steering the wheels of one axle. Brake actuators are actuated using the braking intervention signal or a plurality of braking intervention signals. The stabilizing device is preferably what is referred to as a steer-by-wire controller. The stabilizing device can however also form a component of a driving dynamics controller of the  
15 vehicle.

Advantageous embodiments of the invention emerge from the dependent claims and from the description.

The stabilizing device additionally expediently takes into account the current attitude angle of the vehicle. The attitude angle is the angle between the  
20 longitudinal axis of the vehicle and the vector of the speed of the vehicle. The attitude angle signal which represents the attitude angle of the vehicle is made available by the correspondingly designed actual value means. The limiting means expediently contain attitude angle means for determining a second

attitude-angle-dependent limiting yaw rate signal. The limiting means limit the value of the setpoint yaw rate to the value of the tilt-angle-dependent yaw rate or the attitude-angle-dependent yaw rate, depending on which of the two yaw rates is lower.

5       The known stabilizing device is primarily intended to prevent the vehicle from skidding. However, it is also problematic if the vehicle tilts and possibly even rolls over.

An object of the present invention is therefore to improve a stabilizing device or a method of the type mentioned at the outset to the effect that a risk of 10 tilting of the vehicle is reduced.

In order to achieve the object, with the aforementioned type of stabilizing device there is provision for the stabilizing device to have actual value means for making available a tilt angle signal which represents the current tilt angle of the vehicle, for the limiting means to contain tilt angle means for determining the 15 limiting yaw rate signal by reference to the tilt angle signal, and for the stabilizing device to have generating means for generating a steering intervention signal and/or at least one braking intervention signal by reference to the limited setpoint yaw rate signal. In a corresponding way, a vehicle according to the invention and a method according to the invention are provided.

20       The tilt angle, sometimes also referred to as the rolling angle, describes the rotational deflection of the vehicle about its longitudinal axis. Taking into account the tilt angle in the determination of the setpoint yaw rate signal which is the maximum permitted prevents the vehicle from tilting or even rolling over.

The generating means are, for example, a yaw rate controller. The steering intervention signal controls, for example, a steering actuator for steering the wheels of one axle. Brake actuators are actuated using the braking intervention signal or a plurality of braking intervention signals. The stabilizing device is 5 preferably what is referred to as a steer-by-wire controller. The stabilizing device can however also form a component of a driving dynamics controller of the vehicle.

Advantageous embodiments of the invention emerge from the dependent claims and from the description.

10 The stabilizing device additionally expediently takes into account the current attitude angle of the vehicle. The attitude angle is the angle between the longitudinal axis of the vehicle and the vector of the speed of the vehicle. The attitude angle signal which represents the attitude angle of the vehicle is made available by the correspondingly designed actual value means. The limiting 15 means expediently contain attitude angle means for determining a second, attitude-angle-dependent limiting yaw rate signal. The limiting means limit the value of the setpoint yaw rate to the value of the tilt-angle-dependent yaw rate or the attitude-angle-dependent yaw rate, depending on which of the two yaw rates is lower.

20 The tilt angle signal may contain the current tilt angle of the vehicle. However it is also contemplated for the tilt angle signal to contain values from which the tilt angle can be determined. In principle, the same also applies to the attitude angle signal which may specifically contain the current attitude angle of

the vehicle. However it is also possible for it to contain values from which the vehicle attitude angle can be determined, for example inter alia the lateral speed of the vehicle and the longitudinal speed of the vehicle.

One selection method has proven advantageous for the limiting means: the 5 limiting means. Namely, the setpoint yaw rate signal as an input signal for the generating means if the value of the input signal does not exceed the value of the (first) tilt-angle-dependent limiting yaw rate signal and otherwise the limiting yaw rate signal, that is to say the maximum value of the yaw rate which is responsible for the driving stability of the vehicle. If the second limiting yaw rate 10 signal which is dependent on the attitude angle of the vehicle is additionally made available to the limiting means, the limiting means select, for example, the yaw rate signal which is smallest in absolute value as an input yaw rate signal for the generating means, for example the yaw rate controller.

The above-referenced term yaw rate signal is used in conjunction with 15 the setpoint yaw rate signal and the limiting yaw rate signal. That is, the yaw rate signal is a signal which represents a preset value and which corresponds either to the setpoint yaw rate signal or the limiting yaw rate signal depending on what the selection has yielded. If the term yaw rate signal is used, setpoint yaw rate signals or limiting yaw rate signals are meant. The significance 20 presented here for the two terms yaw rate signal or yaw rate signals is also intended to apply to their use below.

The presetting means are expediently based on at least one reference model of the vehicle. This may be, for example, an essentially real image of the

vehicle.

However, it is also contemplated for a desired behavior of the vehicle, for example a sporty or comfortable desired behavior to be selected as a reference model. In one expedient embodiment of the invention, such desired models can 5 also be selected by a driver of the vehicle.

A reference model is composed, for example, of one or more differential equations which describe the behavior of the vehicle.

The actual value means expediently contain measuring means and/or estimating means. The measuring means are, for example, the vehicle sensor 10 systems, for example rotational speed sensors, a yaw rate sensor, lateral acceleration sensors or the like. The estimating means preferably contain an "observer". The observer is expediently not linear. The observer is, for example, what is referred to as a Kalman filter.

The actual value means accordingly make available real and/or estimated 15 actual values. These actual values expediently form input values for the limiting means and contain, for example, the tilt angle signal and/or the attitude angle signal. Of course, such an observer can also form a component of the limiting means.

The actual value means are expediently connected directly to the 20 generating means. The actual value means advantageously make available input values for the generating means. It is also expedient for the generating means to make available input values for the actual value means.

The yaw rate signals are advantageously dependent on the direction of

rotation. For example, a negative value of a yaw rate signal is available for left-handed rotation and a positive value is available for right-handed rotation of the vehicle about its vertical vehicle axis. In a corresponding way, limiting means are designed to limit the setpoint yaw rate signal in terms of absolute value. For 5 example, the tilt angle means and the attitude angle means in such a configuration respectively make available a positive and a negative maximum limiting yaw rate value. The lower and the upper limiting values may be contained in the first, tilt-angle-dependent or the second, attitude-angle-dependent limiting yaw rate signal. The same applies correspondingly to the 10 setpoint yaw rate signal generated by the presetting means.

The stabilizing device according to the invention is expediently such that the vehicle does not roll over while taking into account the maximum yaw rate. Correspondingly, the limiting means are able to determine the limiting yaw rate signals which are necessary to avoid a vehicle rollover.

15 The several means of the stabilizing device according to the invention may be embodied using hardware and/or software. The stabilizing device expediently contains program code which can be executed by a control, in particular a processor, a driving stability controller and/or a steering controller of the vehicle. The steering controller is, for example, the steering system of a steer-by-wire 20 system.

The stabilizing device according to the invention is preferably applied in multitrack vehicles, for example passenger cars or utility vehicles. The stabilizing device can also be used in single-track vehicles, for example

motorbikes.

The setpoint yaw rate signal is advantageously determined as a function of a preset steering angle signal and a variable which represents the speed of the vehicle. The determination can be carried out using a mathematical model which  
5 is based, for example, on the Ackermann relationship.

Other objects, advantages and novel features of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

10 Brief Description of the Drawing

The sole figure is a schematic diagram showing a vehicle having a stabilizing device according to the invention.

Detailed Description of the Drawing

15 A vehicle 10, for example a passenger car with an internal combustion engine (not illustrated) has a front axle 11 with steerable wheels 12, 13 and a rear axle 14 with non-steerable wheels 15, 16. Brakes 17, 18, 19, 20 for braking the respective wheel 11, 12, 15, 16 and rotational speed sensors 21 to 24 for sensing the respective rotational speed of the wheel 11, 12, 15, 16 are arranged  
20 on the wheels 12, 13, 15, 16. The brakes 17 to 20 can be controlled by a stabilizing device 25 by braking intervention signals 26 to 29 (represented schematically by arrows). The rotational speed sensors 21 to 24 transmit, to the stabilizing device 25, rotational speed signals 30 to 33 which represent the

respective rotational speed of the wheel 12, 13, 15, 16.

A driver 36 can predefine a direction request  $\delta_H$ , which is sensed by a steering angle sensor 37, at a steering wheel 35 or some other steering handle.

The steering angle sensor 37 generates a preset steering angle signal 38 and

5 transmits that signal to the stabilizing device 25. The stabilizing device 25 generates, inter alia, a steering angle signal 39 while taking into account the preset steering angle signal 38, and transfers the steering angle signal 39 to a steering actuator arrangement 40, which contains, for example, an actuating motor or the like. The steering actuator arrangement 40 steers the wheels 12, 13  
10 of the front axle 11. In principle, the stabilizing device 25 could also send a steering intervention signal (not illustrated in the figure) to a steering actuator (not illustrated) which is assigned to the rear axle 14, for example if the vehicle  
15 were to have a rear-axle steering system and/or a combined front-axle or rear-axle steering system.

15 The stabilizing device 25 contains here what is referred to as a steer-by-wire control circuit with presetting means 41, a yaw rate controller 42 which forms generating means according to the invention, sensing and outputting means 43 and an observer 44. In addition, limiting means which are referred to overall by the reference number 45 and which contain tilt angle means 46,  
20 attitude angle means 47 and selection means 48 are present.

The stabilizing device 25 is based, for example, on a vehicle model with three degrees of mechanical freedom. In addition to the attitude angle  $\beta$  and the yaw rate  $\psi$ , the rolling angle  $\varphi$  describes the current position of the vehicle 10.

The following movement equations (1)-(3) of the vehicle 10 can be derived from the law of momentum in the lateral direction and the law of conservation of angular momentum about the vertical axis and the longitudinal axis of the vehicle 10. In this context, variables which are transformed to a horizontal coordinate system are used to describe the state of the vehicle.

$$\dot{\beta} = -\psi + \frac{1}{mv_x} \{ F_{s,v} + F_{s,h} \} \quad (1)$$

$$\ddot{\psi} = A(\psi, \varphi, \dot{\varphi}) + B(\varphi) \{ l_v F_{s,v} - l_h F_{s,h} - M_{\psi\varphi} \} \quad (2)$$

$$\ddot{\varphi} = C(\psi, \varphi, \dot{\varphi}) + D(\varphi) \{ F_{s,v} + F_{s,h} \} \quad (3)$$

In the equations (1) to (3),  $F_{s,v} + F_{s,h}$  are the side forces at the front axle and the rear axle and  $l_v$  and  $l_h$  are the distances between the center of gravity and the front axle and rear axle, respectively. The functions A and C describe non-linear elements which can be compensated by control technology. The function B corresponds approximately to the tilt-angle-dependent reciprocal value of the moment of yaw inertia. The function D corresponds approximately to the tilt-angle-dependent quotient formed from the height of the center of gravity and the moment of rolling inertia.

In vehicles which can be steered at the front axle, the lateral force can be changed directly at the front. The lateral force of the rear axle can be influenced by a braking intervention and/or by steering the rear axle. Otherwise, the lateral

force occurs at the rear owing to vehicle parameters, tire parameters and ambient parameters. The control approach which is selected by way of example is based on a front axle steering system with an optional single-wheel braking intervention, for example by the braking intervention signals 26 to 29. The 5 present design of the yaw rate controller 42 or of the tilt angle means 46 is expediently made using methods of non-linear control technology, for example with a Ljapunov function.

In the stabilizing device 25, the Ljapunov function V is, for example as follows:

10

$$V = \frac{1}{2}(\dot{\psi} - \dot{\psi}_{Soll})^2 + \frac{1}{2}k_1(\dot{\phi} - \dot{\phi}_{Soll})^2 + \frac{1}{2}k_2(\varphi - \varphi_{Soll})^2, \quad k_1, k_2 > 0 \quad (4)$$

For the stability of the overall system it is required that the function V be positively semidefinite and its time derivative be negatively definite. The 15 following therefore results:

$$V \geq 0, \quad \dot{V} < 0 \quad (5)$$

20 If the movement equations (1) to (3) are inserted into the Ljapunov function (4), a feedback law can be established for the yaw rate controller 42,

$$V \geq 0, \dot{V} < 0$$

(5)

5 If the movement equations (1) to (3) are inserted into the Ljapunov function (4), a feedback law can be established for the yaw rate controller 42, said that law compensating the non-linear components and being stabilized by linear components. This results in the following formula:

$$F_{sv} = \frac{1}{D(\phi)(l_v + l_H)} \{ -A(\psi, \varphi, \dot{\varphi}) + B(\phi)I_H m a_y + \dot{\psi}_{soll} - \lambda_1 (\psi - \psi_{soll}) \} \quad (6)$$

10

The yaw rate controller 42 can generate the steering intervention signal 39, which contains a wheel steering angle, from the lateral force at the front axle  $F_{sv}$ .

15 In a way which is analogous to the lateral force at the front axle  $F_{sv}$ , a setpoint yaw rate  $\Psi_{soll}$  at which the overall system experiences transient recovery in a stable fashion about a tilt angle  $\varphi$  can also be determined from the Ljapunov function (4). The following formula (7) forms the basis for the tilt angle means 45 which can also be referred to as a tilt angle limiting controller.

20

movement of the vehicle 10 only when there is the risk of tilting or rollover of the vehicle 10. The function of the attitude angle means 47, which can also be referred to as an attitude angle limiting controller in the present case, remains uninfluenced by the use of the tilting angle means 46 and the selector means 48.

- 5 In a highly simplified way it is possible to state that the attitude angle means 47 prevent skidding of the vehicle 10, and the tilt angle means 46 prevent tilting of the vehicle 10 in conjunction with the selector means 48. In this context, the selector means 48 assume a limiting function, which will be explained in more detail below.

10 The presetting means 41 form a setpoint yaw rate signal 49 with reference to the preset steering angle signal 38 and a variable which represents the speed of the vehicle. The variable which represents the speed of the vehicle is, for example, contained in a driving state signal 56 which will be described below. This setpoint yaw rate signal 49 generally forms the input variable for the yaw rate controller 42. However, the steering request of the driver 36 cannot be implemented in the desired way in every driving situation of the vehicle 10. The setpoint yaw rate signal 49 is monitored by the limiting means 45 and if necessary limited to a limiting yaw rate signal. In the present case, the selector means 48 are provided with a first limiting yaw rate signal 50 by the tilt angle means 46 and with a second limiting yaw rate signal 51 by the attitude angle means 47, with the second limiting yaw rate signal depending on the current attitude angle rate of the vehicle 10. The selector means 48 select the setpoint yaw rate signal 49 if it is smaller in absolute terms than the limiting yaw rate

signals 50, 51. Otherwise, the selector means 48 select the limiting yaw rate signal 50 or 51 which is smaller in absolute terms.

The yaw rate signals 49 to 51 are dependent on the direction of rotation here, that is to say they are provided, for example, with a sign. This applies both 5 to the setpoint yaw rate signal 49 and to the limiting yaw rate signals 50 ~~and~~, 51. Correspondingly, the limiting yaw rate signals 50, 51 each contain an upper limiting value and a lower limiting value. It would also be possible to use the term limiting yaw rate for a right-handed bend or a limiting yaw rate for a left-handed bend, and these are respectively defined by the tilt angle means or 10 the attitude angle means 46, 47. The yaw rate controller 42 generates output signals 52 which may contain, for example, the steering intervention signal 39. The output signals 52 are sensed by the sensing and output means 43 and transferred to the actuator system of the vehicle 10, for example the brakes 17 to 20. The sensing output means 43 output, for example, the braking intervention 15 signals 26 to 29 and sense the rotational speed signals 30 to 33.

The sensing means 43 and the observer 44 form components of actual value means 53. The actual value means 53 measure and estimate system states of the vehicle 10, in which case they evaluate, for example, the rotational speed signals 30 to 33 in order to determine the lateral speed and longitudinal speed of 20 the vehicle 10. Non-measurable system values, which may, however, be required, for example, by the tilt angle means 46, are determined, as it were estimated, by the observer 44, which can accordingly also be referred to as an estimating means.

The observer 44 contains, for example, a Kalman filter and estimates, for example, an attitude angle, a tilt angle, a tilt angle speed or the like of the vehicle 10 by reference, for example, to the steering angle, the longitudinal speed of the vehicle, the lateral acceleration and a yaw rate which the sensing means 5 43 transmit to the observer within the scope of a signal 57. However, in principle the spring paths at the wheels 12, 13, 15, 16 until one of the wheels lifts off could also be determined so that it would be possible to determine the tilt angle and tilt angle rate as measured variables.

The current yaw rate of the vehicle 10 is determined by a yaw rate sensor 10 55 and this is transferred to the stabilizing device 25 within the scope of an actual yaw rate signal 54.

The observer 44 sends a driving state signal 56 to the presetting means 41 and the attitude angle means 47 and the tilt angle means 46. The driving state signal 56 contains, for example for the tilt angle means 46, the current tilt angle 15 and/or the current tilt angle rate of the vehicle 10. For the attitude angle means 47, for example the attitude angle and/or the attitude angle rate and/or the longitudinal speed of the vehicle and the lateral speed of the vehicle 10 are contained in the driving state signal 56 of the vehicle 10. The driving state signal 56 contains, for example, a tilt angle signal and an attitude angle signal. The 20 longitudinal speed of the vehicle which is contained in the driving state signal 56 and which constitutes a variable which represents the speed of the vehicle is fed to the presetting means 41 for determining the setpoint yaw rate signal 49.

The yaw rate controller 42 and the observer 44 are also expediently

connected directly to one another. This optional configuration of the stabilizing device 25 is therefore shown in dashed lines. The observer 44 transfers the driving state signal 56 to the yaw rate controller 42. In the reverse direction, the yaw rate controller 42 transfers its output signals 52, that is the presetting 5 variables for the vehicle actuator system, to the observer 44.

The driving state signal 56 whose contents are determined and/or estimated by the actual value means 53 can also contain further signals, for example the longitudinal inclination and/or the lateral inclination of the underlying surface on which the vehicle 10 is moving. It is also possible, for 10 example, for what is referred to as a Correvit sensor, which can determine the lateral speed of the vehicle and longitudinal speed of the vehicle or alternatively the attitude angle of the vehicle 10, to be provided at the vehicle 10.

The foregoing disclosure has been set forth merely to illustrate the invention and is not intended to be limiting. Since modifications of the disclosed 15 embodiments incorporating the spirit and substance of the invention may occur to persons skilled in the art, the invention would be construed to include everything within the scope of the appended claims and equivalents thereof.